PLANET IN A BOTTLE

Planet in a Bottle Activity[1], The Extreme Planet Project and other Extremophile Teaching Resources

LESSON SUMMARY

In this activity, students learn the basic principles behind the Goldilocks zone, extremophiles, and astrobiology through a reading, two experiments, and a project.

Planet in a Bottle Part One demonstrates the Goldilocks zone concept through a reading and experiments that examine a simplistic model of three planets: one cold, one hot and one temperate. The models consist of plastic soda bottles capped by latex balloons. Each bottle contains a mixture of sugar, water and yeast. As the yeast metabolize the sugar in the bottle, they release CO_2 gas, inflating the balloon. Students measure the balloon circumference for all three planet models as a means of determining the suitability of the planet for life. (The temperate bottle allows the yeast to grow in moderate conditions, analogous to the Earth's position in the Goldilocks zone.)

A lab report and discussion questions help students focus on the scientific method, develop a hypothesis, reflect on variables, and understand the concepts demonstrated by the experiments.

In Part Two, students explore the impact of less temperate and less hospitable environments by creating their own bottle models to serve as analogs for the extreme conditions found on other planets and moons in the solar system, or in hot springs in Yellowstone National Park.

MONTANA STATE UNIVERSITY
Astrobiology Biogeocatalysis Research Center

In the **Extreme Planet Project*,** students explore two different NASA web resources that allow them to design planets by adjusting various planetary variables. Students then use the programs to design their own planet and use their knowledge of extremophiles to create an extremophile adapted to live on it. They draw a diagram of their planet and its extremophile inhabitant to present to their class and then write a newspaper article about their discovery.

**Note that this part of the project requires access to computing resources and the internet.*

Alternative activities

Activities that take less time or do not require computer access include:

What Can Life Tolerate? This activity requires students to read then do some critical thinking about extremophiles. Then they play a fun card game to match the extremophile with its earth and extraterrestrial environment. A copied version is at the end of this document, however the original PDF (which also has other activities) can be found at: http://teachspacescience.org/graphics/pdf/10000406.pdf

Short videos about extremophiles:
http://www.pbs.org/wgbh/nova/teachers/space/extreme-environments.html
http://www.pbs.org/wgbh/nova/teachers/space/arctic-seafloor.html

Video about extremophiles at Yellowstone:
http://www.youtube.com/watch?v=rz-cqKbHh04

Extremophiles with NASA scientist:
http://www.youtube.com/watch?v=pdq_JoNoOGs

Extremophiles in Yellowstone, interactive panoramas of thermal features of YNP that feature clickable extremophile facts:
http://hydrogen.montana.edu/yspano.html

Any combination of these activities can be used in the classroom to learn about extremophiles.

1. This experiment is modified from one posted on the NASA Science News website in 2002. As of 2011 it could be found at http://science.nasa.gov/science-news/science-at-nasa/msad16mar99_1a/

LEARNING OBJECTIVES

- Students will understand the concept of the “Goldilocks zone,” the conditions on other planets and moons in the solar system, and how extremophiles challenge what we think of as habitable.
- Students will demonstrate the concept of the “Goldilocks zone” idea by creating a “planet in a bottle” as a very simple model of cold, hot, and temperate planets.
- Students will utilize the planet model as a point of comparison for exploring how environmental variables impact the growth of yeast and by extension how environmental conditions challenge life on Earth and potentially elsewhere in the universe.
- Students will experience the scientific method through the process of constructing and testing a hypothesis, identifying and manipulating experimental variables, developing and testing methods, as well as creating and critically evaluating experimental analogs to model actual planets/moons.
- Students will become comfortable and familiar with the format and content of a basic lab report.
- Students will demonstrate the impact of harsh environmental conditions like those found on Mars, Venus, Europa, and Titan on simple living things (yeast) by constructing their own variations on the Earth model.
- Students will design a planet using web resources and learn about the impact of type of local star, astronomical distance, and other factors on the habitability of the planet.
- Students will design a planet and an extremophile adapted to live on that planet and write a report about the planet and extremophile.

GRADE LEVEL

Appropriate for grades 5-12 in both formal and informal educational settings.

TIME REQUIRED

- **Goldilocks Zone Reading and Matching Extremophiles**

  20-30 minutes

- **Planet in a Bottle Experiment: Demo or student experiment**

  30-90+ minutes (depending on whether run as a demo or student experiment)

- **Extreme Planet in a Bottle: Student experiment**

  20-45 minutes class time plus student time outside of class to research and collect materials.

- **Extreme Planet Project**

  30 minutes for designing planets with the websites

  30 minutes to 1 hour+ for drawing diagrams and writing the newspaper article (depending on student abilities).

BACKGROUND CONTENT

Earth science: This lesson assumes that students know that the Earth is unique in the solar system because of its moderate temperatures and wide range of biomes.

Space science: A basic knowledge of the planets of the solar system and their moons will be helpful but is not critical.

Biology: This lesson assumes students have basic knowledge of major biomes of the Earth, know that organisms have basic needs to survive, and know that organisms are adapted to live in different environmental conditions.

Scientific Method: This lesson reinforces the basics of the scientific method. Some familiarity with the scientific method and the concept of variables is helpful but not necessary.

NEXT GENERATION SCIENCE STANDARDS

Earth's Place in the Universe – Grade 5

- **5-ESS1-1.** Support an argument that the apparent brightness of the sun and stars is due to their relative distances from Earth. [Assessment Boundary: Assessment is limited to relative distances, not sizes, of stars. Assessment does not include other factors that affect apparent brightness (such as stellar masses, age, stage).]

Matter and Energy in Organisms and Ecosystems – Middle School

- **MS-LS2-1.** Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. Emphasis is on cause and effect relationships between resources and growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.
- **MS-LS2-4.** Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. Emphasis is on recognizing patterns in data and making warranted inferences about changes in populations, and on evaluating empirical evidence supporting arguments about changes to ecosystems.

Growth, Development, and Reproduction of Organisms – Middle School

- **MS-LS1-4.** Use an argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively. Examples of behaviors that affect the probability of animal reproduction could include nest building to protect young from cold, herding of animals to protect young from predators, and vocalization of animals and colorful plumage to attract mates for breeding. Examples of animal behaviors that affect the probability of plant reproduction could include transferring pollen or seeds, and creating conditions for seed germination and growth. Examples of plant structures could include bright flowers attracting butterflies that transfer pollen, flower nectar and odors that attract insects that transfer pollen, and hard shells on nuts that squirrels bury.
- **MS-LS1-5.** Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms. Examples of local environmental conditions could include availability of food, light, space, and water. Examples of genetic factors could include large breed cattle and species of grass affecting growth of organisms. Examples of evidence could include drought decreasing plant growth, fertilizer increasing plant growth, different varieties of plant seeds growing at different rates in different conditions, and fish growing larger in large ponds than they do in small ponds.

Interdependent Relationships in Ecosystems – High School

- **HS-LS2-6.** Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and, extreme changes, such as volcanic eruption or sea level rise.

Anticipatory set

- To introduce this lesson explain to your students that frequently scientists refer to the Earth as existing in the "Goldilocks zone" in the solar system; an area that is not too hot (not too close to the Sun) and not too cold (not too far from the Sun) but just right for life. Although there are obviously other factors important to life, the distance from a star has considerable influence because it determines whether liquid water can exist on the planet and this is something that all Earth-life requires in some quantity.
- Distance from a star also impacts whether solar energy is in abundant enough supply to support photosynthetic life, the base of the majority of Earth's food webs. Therefore, as NASA scientists and other researchers look for planets capable of harboring life in other solar systems they tend to look for planets that are in that solar system's Goldilocks zone because that plays such an important role in the ability of Earth to sustain life.
- Explain to the students that this reading and activity will help them to understand the Goldilocks zone concept and learn about the influence of temperature on simple organisms. They can also use model planets to test some habitability limits. Challenge them to come up with their own extreme planet model to test.

Extensions

- **Planet in a Bottle –** An extension for older or more advanced students is to have them actually write their own lab report for their own version of the planet experiment rather than use the one provided.
- **What Can Live Tolerate?** Worksheet at the end of this document.
- **Life on the Edge** Card game at the end of this document.

The Goldilocks Zone

READING

This reading can be used to open the lesson, or can used during the experiment, between recording the size of the balloons. The reading covers the concept of the Goldilocks zone, discusses extremophiles that seem to violate the Goldilocks concept or challenge what we consider "habitable," and discusses the conditions on other planets and moons in our solar system that may have the potential to harbor life. It is a great way to generate discussion with your students.

Planet in a Bottle: Part 1

Note: *This activity can be conducted as an all-class demo or students can do it individually or in groups.*

SUMMARY

For this demonstration, you will fill three bottles with a nutrient solution and yeast. You will cap each bottle with a balloon to capture any CO_2 the yeast creates through its metabolic processes. The control bottle will be filled with warm tap water, the first experimental bottle will be filled with boiling water and kept in a hot water bath and the second experimental bottle will be filled with cold water and kept in an ice water bath. Throughout the experiment students will record the circumference of the balloon for each bottle at 10 minute intervals.

LAB REPORT

Students are given a simple lab report format to fill out to help reinforce the scientific method. The students are asked to write the objective of the experiment, to state a hypothesis, to list the materials and procedure, to record results in a data table, to draw a diagram of their initial and final observations of the three bottles, and to answer discussion questions. There are several options for having students create the procedures, depending on the age and abilities of the students or time constraints. You may have them copy them down from the board. You may give them out of order and ask the students to figure out the correct order. You may have the students observe you setting up the experiment and have them write up the procedures you used. The questions in the discussion section are meant to help students reflect on the experimental results and the overall meaning of those results in understanding the Goldilocks concept.

MATERIALS

- Three 12 or 20 oz. plastic soda bottles
  (12 oz bottles show the most dramatic results.)
- 9 sugar cubes (3 for each bottle)
- 3 packets quick rise yeast (one for each bottle)
- 1 cup warm tap water (no greater than 30C)
- 1 cup cold tap water
- 1 cup boiling water
- 2 bowls or beakers large enough to hold a bottle in an ice water bath and a hot water bath (a 500ml beaker works well)
- 1 cup of ice
- one hot plate
- 3 standard (9 inch) latex balloons (stretch before using)
- adhesive tape (duct tape works best)
- measuring tape or string and meter stick
- stopwatch or timer
- 1 cup measuring cup

PROCEDURE

1. Starting with three clean, empty soda bottles. Label one of the bottles "boiling water," another "warm water," and the third "cold water."
2. Fill each bottle with 1 cup of the appropriate temperature water.
3. Add 3 sugar cubes to each bottle and swirl until dissolved.
4. Add 1 packet of yeast to each bottle.
5. Gently stretch the balloons and then cap each bottle with a balloon so that air from the bottle can move freely into the balloon. (You can test this by gently squeezing the bottle, the balloon should inflate slightly and then deflate when the bottle is released.)
6. Check to be sure the balloon covers the bottom lip of the bottle evenly and then tape the bottom edge of the balloon to the bottle so that no air can escape.
7. Place the cold water bottle in an ice water bath.
8. Place the boiling water bottle in the hot water bath (on a hot plate to maintain high temperature, boiling is not necessary, but *hot* is).
9. Start the timer.
10. Using string and a meter stick or a cloth measuring tape, have students record the circumference of the balloon every ten minutes in the data table provided.

11. Have students draw a picture of all three balloons at the beginning and end of the experiment for their results section.
12. Have students fill in the lab report sections between balloon circumference measurements. Use the time between observations to discuss the lab report, experiment, and the scientific method. You may want to have students brainstorm on what they want to construct or model with their individual planet in a bottle activity.

Note: *The temperate bottle balloon (the model of Earth) will reach maximum inflation in 2-3 hours but there will be visible results in 5-10 minutes.*

Planet in a Bottle: Part 2

STUDENT EXPERIMENT

In Part Two of the planet in a bottle activity, students are challenged to expand on the ideas from Part One and design their own experiment. They are encouraged to develop either a model for one of the planets or moons in our solar system, or for a Yellowstone hot spring, or to identify a single variable to test. This activity works well as a group or partner activity, particularly with younger students. Below is a list of ideas for models of various planets and moons modified from the original Science@NASA lesson plan. Also included are ideas for single variable modifications of the experiment. Obviously, the materials necessary will vary. A simple lab report in the same format as the first experiment is included in the student workbook.

IDEAS FOR MODELING OTHER PLANETS AND MOONS IN OUR SOLAR SYSTEM

- **Mercury in a Bottle**: Boil the water before adding sugar and yeast.
- **Venus in a Bottle:** Instead of water and sugar, use scalding hot orange juice as a nutrient mix. Citric acid in the juice represents sulfuric acid in Venus's hot atmosphere. Lemon juice or vinegar can also be used to increase the acidity of the nutrient mix. Venus's atmosphere also has a high pressure, so the simulation can be made more realistic by heating the nutrient mix in a pressure cooker.
- **Moon in a Bottle:** Expose the yeast to a vacuum, using a hand pump bell jar, and to radiation from a microwave oven and/or a UV lamp.
- **Mars in a Bottle:** Freeze the yeast, then expose the microbes to ultraviolet radiation from a UV lamp before adding yeast to the nutrient mix.
- **Europa in a Bottle:** Freeze a briny mixture of water and Epsom salt. Break the ice into chips and mix the salty ice chips with a cold nutrient solution.
- **Callisto in a Bottle:** Add common table salt or Epsom salts to the nutrient mix to simulate a salty environment.
- **Pluto in a Bottle:** Freeze the yeast in a deep freezer before adding to the nutrient mix.
- **Octopus Springs in a Bottle:** Add baking soda to hot water, test with a pH strip to pH 8 or 9. Keep in a hot bath around 60° C*
- **Norris geyser basin in a Bottle:** Add Epsom salt and hydrochloric acid or sulfuric acid and table salt to hot water. Norris contains sulfates and chlorides.*

**Follow http://microbewiki.kenyon.edu/index.php/Yellowstone_Hot_Springs to find out more about the extremophiles in these specific geysers*

SINGLE VARIABLE MODIFICATIONS

For these modifications, have students compare their results with the room temperature experiment from Part One.

- Low nutrient: Use one sugar cube rather than three to make the nutrient mix.
- High nutrient: Use six sugar cubes to make the nutrient mix.
- Low water: Use half a cup of water to make the nutrient mix.
- Ultra low water: mix sugar with just enough water to make a paste, stir the yeast into the nutrient paste and then add to the bottle.
- High water: Fill the bottle completely with water after adding the sugar and yeast.
- Frozen yeast: Freeze the yeast for 24 hours prior to the experiment.
- UV exposure: Expose yeast to black light for 24 hours prior to the experiment.
- Detergent: Mix several drops of detergent into the nutrient mix.
- Saline: Mix in 1-4 tablespoons of salt into the nutrient mix.
- Ultra cold: Mix rock salt into ice bath for the bottle. Compare results to cold bottle in Part One rather than the temperate bottle.
- Different yeast: Change the type of yeast used.
- Vitamin: Add a ground up multivitamin to the nutrient solution.

Extreme Planet Project

For this activity, students will use web resources to become familiar with the attributes of a planet that influence the conditions found there, particularly habitability. NASA has two excellent websites that allow students to manipulate planetary variables and observe the outcomes. This activity asks them to play around on both websites and ultimately design a planet and an extremophile that lives there.

DESIGN A PLANET ON NASA'S ASTROVENTURE WEBSITE

1. Go to the AstroVenture "Design a Planet" website, which can be found at http://astroventure.arc.nasa.gov/DAP/index.html
2. After watching the introduction, click on the "Design a Planet Tutorial" and find out how to use the website to make your planet.
3. Once you feel confident that you understand the process, try your hand at making a planet by choosing "Design a Planet Regular or Lite." Be sure to read the text boxes for each characteristic of your planet so that you understand their role in making a planet habitable or uninhabitable.
4. Try designing a planet several times and see what types of planets are created by different combinations of characteristics.

DESIGN A PLANET ON NASA'S JPL EXTREME PLANET MAKEOVER WEBSITE

1. Go to the Jet Propulsion Laboratory's Extreme Planet Makeover website, found at http://184.72.55.19/system/interactable/1/index.html or navigate there by going to http://planetquest.jpl.nasa.gov/
2. Design a planet by adjusting the planetary attributes (found at the bottom of the page). Again, be sure to read the text boxes that appear as you scroll over each of the options so that you can understand how each attribute influences the planet you create.
3. Play around with the attributes and see what types of planets you can create.

DESIGN YOUR OWN PLANET

- Design a planet on Astroventure or Extreme Planet Makeover.
- Name your planet and describe its characteristics such as AU (astronomical unit, roughly the mean distance between the Earth and Sun) from a star, size, average temperature, presence or absence of plate tectonics, whether it is a rocky planet or gas planet, whether it has an atmosphere or not (write these facts down from Astroventure or Extreme Planet Makeover).
- Use your knowledge of your new planet and Earth extremophiles to design an extremophile that lives on your planet.
- *Note: Just because your planet couldn't support human life doesn't mean that an extremophile can't live there. You are free to make any type of planet as long as you can explain how your extremophile is able to live on it.*
- Draw a picture of your planet and its extremophile.
- Write up some facts about your planet and extremophile and prepare to present your creation to your classmates. Here are some ideas to get you thinking about the kinds of details you will want to include.

QUESTIONS ABOUT YOUR PLANET:

- What is the name of your planet?
- What is it like on the surface of your planet?
- Could humans survive on its surface? Why or why not?
- Is there water there? Is it liquid, ice, gas?
- Is there weather on your planet?
- Is the climate the same everywhere on your planet or does your planet have different climates?
- Are there oceans?

QUESTIONS ABOUT YOUR EXTREMOPHILE:

- How big is your extremophile?
- How does your extremophile get energy? (Does it get it from the sun, from eating other things, from using chemicals found on your planet?)
- How does your extremophile interact with its environment?
- Is it the only form of life on your planet?
- What special adaptations help the extremophile cope with life on your planet?
- Could your extremophile survive on Earth?

NEWSPAPER ARTICLE

Extra! Extra! Life found on another planet!!!

- Write a newspaper article about your planet and its extremophile.
- Be sure to make your story a good summary of the information that includes the *who, what , when, where, why,* and *how* found in any good news story. Remember that if this was a real story, it would be huge news so make your story exciting.
- Keep in mind the questions about your planet and extremophile (listed above) when writing your article so that you can give your readers lots of cool details.
- Major news stories often include pictures, so include a picture of your planet and it's extremophile in your article.

Alternative Activities

Activities that take less time or do not require computer access are listed on the first page of this document. The **What Can Life Tolerate?** activity follows.

WHAT CAN LIFE TOLERATE?

This activity requires students to read then do some critical thinking about extremophiles. Then they play a fun card game to match the extremophile with its earth and extraterrestrial environment. A copied version is included on pages 8–19 of this document. The original PDF (which includes additional activities) is at:
http://teachspacescience.org/graphics/pdf/10000406.pdf

ACTIVITY 4

What can life tolerate?

Cold-loving bacteria
COURTESY OF DR. HENRY ALDRICH, UNIVERSITY OF FLORIDA

Collecting cold-loving extremophiles by coring into the Antarctic ice sheet.
COURTESY OF THE NATIONAL SCIENCE FOUNDATION

Our solar system has nine planets and over 60 moons. Of all these worlds, only Earth is known to have life. Consequently, we must base any search for extraterrestrial life on what we know about life here.

Thanks to advancing technology, the past decade has seen the discovery of organisms living under conditions we consider extreme and uninhabitable. These bacteria and bacteria-like organisms are called **extremophiles**. They are **prokaryotes**, a type of very small, single-celled organism that lacks a nucleus. The fact that no one expected to find organisms living under extreme conditions underscores how much we still have to learn about life!

PURPOSE

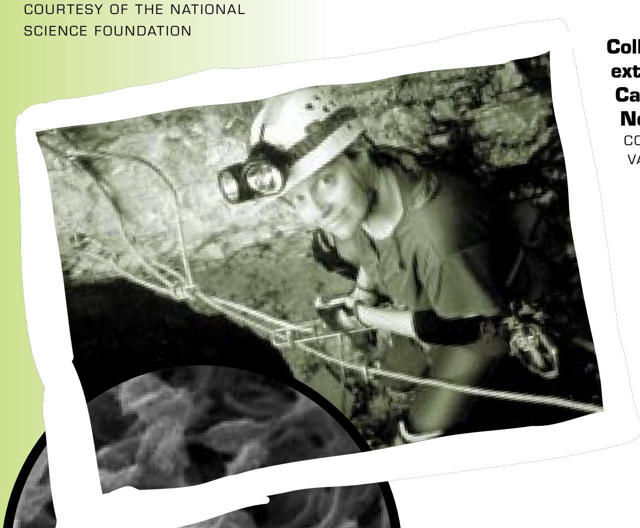
To show that organisms living under extreme conditions on Earth can serve as analogs for extraterrestrial life

CONTEXT

Activity 4 explores some of the reasons to think that extraterrestrial life is possible. In doing so, it draws on concepts developed earlier in the module such as understanding what life is, what it requires, and what makes a planet habitable.

TIME

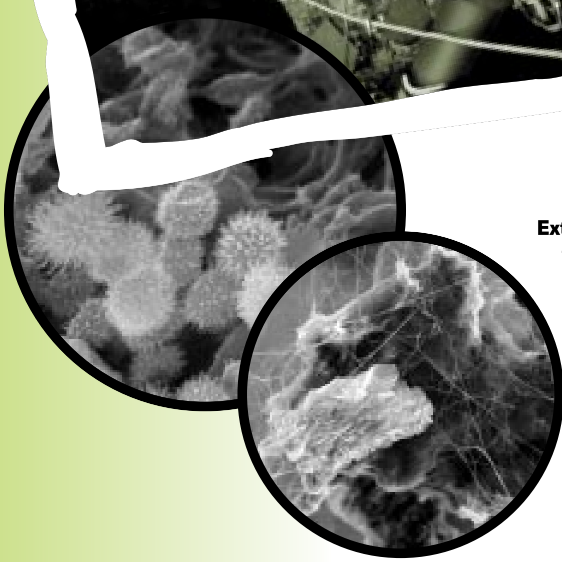
2 to 4 class periods



Collecting acid-loving extremophiles in Carlsbad Caverns, New Mexico.
COURTESY OF VAL HILDRETH-WALKER

Collecting heat-loving extremophiles from a hot spring in Yellowstone National Park.
COURTESY OF MICHAEL MILSTEIN, BILLINGS GAZETTE

Two views of heat-loving bacteria.
COURTESY OF DR. HENRY ALDRICH, UNIVERSITY OF FLORIDA



Extremophiles adapted to cave conditions (e.g., dark, acidic, and low levels of oxygen and nutrients)
COURTESY OF SPILDE, NORTHUP, AND BOSTON

CONCEPTS

- We must base any search for extraterrestrial life on what we know about life on Earth.
- Extremophiles live at the limits of what life's chemistry is able to tolerate.
- Any place that mirrors Earth's life-sustaining environments may harbor life.
- As we explore the solar system, we find evidence for conditions that may support life.
- If extraterrestrial life is found in our solar system, it will most likely be microbial and inhabit environments considered extreme on Earth.

SKILLS

- *Extract* key information from a reading
- *Contribute* thoughtfully to discussions
- *Draw* conclusions and *Make* inferences when creating sets
- *Understand* extremophiles as analogs for extraterrestrial life
- *Conceive* of a plausible mission
- *Debate* the ethics of sending Earth life to another world

MATERIALS

- one Activity Guide (pp. 41–42) for each student
- one set of *Life on the Edge* cards (pp. 46–48) per four students (laminate or copy onto cardstock, if possible)
- poster materials

Extremophiles live at the limits of what life's chemistry is able to tolerate. If organisms on Earth can thrive under such conditions, then one might reasonably expect that similar conditions on other worlds might support life, as well. In fact, as we explore our solar system, we find mounting evidence for extraterrestrial conditions that may support extremophiles.

The logic at work, both in the search for extraterrestrial life and in this activity, is that Earth's extremophiles can serve as models for life elsewhere. It is plausible to think that we may find evidence of life in any place that mirrors Earth's life-sustaining environments.

In this activity, students play a card game that models the logic driving much of the search for extraterrestrial life. In the game, students start with an extreme habitat on Earth, find an extremophile that might live under those conditions, and finally identify a similar extraterrestrial habitat. By grouping these three elements, students realize that promising extraterrestrial habitats, and maybe extraterrestrial life itself, do indeed exist. Additionally, they realize that if extraterrestrial life *is* found in our solar system, it will most likely resemble one of Earth's extremophilic microbes.

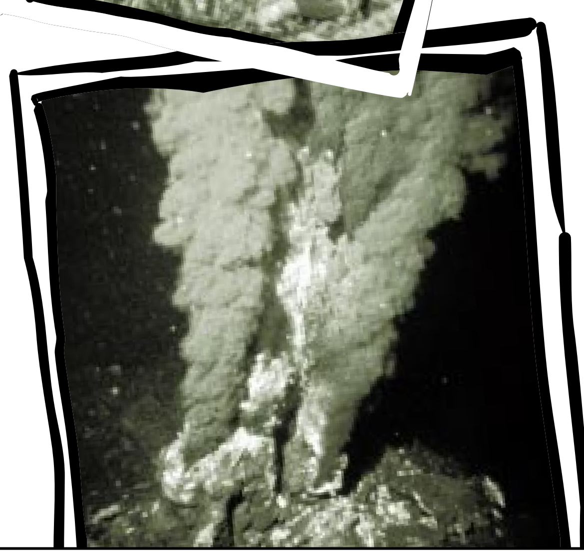
We are in the infancy of being able to detect extraterrestrial life. But daily, we learn more about the limits of life and about extraterrestrial environments and are moving our search forward.

These bacteria extract energy from inorganic chemical sources. They live inside tubeworms by the millions.

COURTESY OF DR. COLLEEN CAVANAUGH, HARVARD UNIVERSITY

These tubeworms are about one meter long. They lack a mouth or gut but are able to absorb chemical-rich seawater to feed the bacteria living in their bodies. The bacteria break down the chemicals, providing energy for themselves and for their tubeworm hosts.

© WOODS HOLE OCEANOGRAPHIC INSTITUTION



Along mid-oceanic ridges, hydrothermal vents spew clouds of chemicals and minerals into the seawater. Bacteria can metabolize these chemicals, forming the base of an entire ecosystem that functions in the absence of sunlight.

COURTESY OF P. RONA OAR/NATIONAL UNDERSEA RESEARCH PROGRAM

Recommended Procedure

STEP **1** Read the Activity Guide (pages 41 to 42) so you are familiar with the information that the students have available.

STEP **2** Have students read the information about extremophiles in the Activity Guide (page 41).

STEP **3** In groups, have students discuss and answer the four questions that follow the reading. Conduct a brief class discussion to make sure students understand:

- **why extremophiles are either bacteria or bacteria-like organisms.**
- **that extremophiles require the extreme conditions to be ongoing and continuous. With extremophiles, we are talking about long-term conditions, not short-term, one-time exposures.**
- **the range of conditions that life can tolerate.**

STEP **4** Teach students the *Life on the Edge* card game. You can do this by having students read the directions on the Activity Guide (page 45) themselves, read and discuss the directions as a class, or demonstrate the game for the class. Make sure they understand:

- **what constitutes a set.**
- **that there are duplicates of the organism cards. A table showing how many of each card are available is printed on the *Life on the Edge* rules sheet.**
- **that the three kinds of cards are linked by a particular environmental condition.**

Emphasize that the habitats described on the *Possible Extraterrestrial Habitat* cards are speculations based on current data. Confirming the existence of most of the features described on these cards requires further exploration.

STEP **5** Have students play two or three rounds of the *Life on the Edge* card game.

The table below shows the make up of the 48 cards in the deck. This table is reproduced on the *Life on the Edge* rule sheet.

Environmental Condition	Number of Organism Cards	Number of Earth Habitat Cards	Number of Possible Extraterrestrial Habitat Cards
Hot	4	4	4
Cold	4	4	4
Acid	2	2	2
Salt	3	3	3
Radiation	3	3	3

To date, no extraterrestrial life has been found in the solar system. Linking specific Earth organisms to extraterrestrial habitats is an exercise in imagining what type of extraterrestrial life might be found based on adaptations that are successful in similar Earth environments.

STEP **6** Base a class discussion on *Think About It* Questions 1 to 7. Students can answer these questions on their own, in groups, as homework, or as a class.

STEP **7** Challenge groups to select a "crew" of extremophiles to send to Mars, Europa, or one of the other top candidates they identified in Activity 3. To have the organisms survive once they reach their destination, groups must select a specific habitat on their target planet or moon and describe a plausible way to deliver the extremophiles to that habitat. Have groups create and then present a poster explaining their mission.

STEP **8** Discuss the ethical issues involved with sending Earth life to another planet or moon and have students debate different positions.

Some would say that sending Earth life to another world contaminates it and seriously compromises learning about how life arises, evolves, and persists on other worlds. They also might say that Earth life might out-compete extraterrestrial life forms and drive them into extinction before we understand them or even know they are there. Merely sending a spacecraft to another world might be enough to damage a sensitive environment with rocket exhaust, physical impact, and Earth materials. Even though NASA takes great pains to sterilize its spacecraft, it is still possible for microbes to "hitchhike" a ride to another world.

Others say that if humans are ever to inhabit other worlds, we need to send microbes now to provide raw materials and change the environment in ways that will support serious colonization. This is called **terraforming**. For example, microbes could help create an atmosphere, add oxygen to the environment, detoxify harmful compounds, extract useful materials from the planet's or moon's crust, and establish a food supply.

The *Life on the Edge* game follows the rules for Rummy. Students can also use the cards to play any card game in which the cards are grouped to make sets. *Concentration* and *Go Fish* are examples of this kind of game.

What can life tolerate?

Activity Guide

Name ________________________________

Date ________________________________

Introduction

Our solar system has nine planets and over 60 moons. Of all these worlds, only Earth is known to have life. Consequently, we must base any search for extraterrestrial life on what we know about life here. Over the past ten years, we have discovered organisms living in places once considered extreme and uninhabitable. These bacteria and bacteria-like organisms are called **extremophiles** (*philia* is Greek for "love"). No one expected to find organisms living under such extreme conditions, which shows how much we still have to learn about life!

If organisms on Earth can thrive under extreme conditions, then couldn't organisms live under similar conditions on other worlds? As we explore the worlds in our solar system, we find evidence for conditions that may support extremophiles. As a result, Earth's extremophiles can serve as models for life elsewhere.

Meet the Champions

Let's meet some extremophiles. Extremophiles not only tolerate extreme conditions (extreme by human standards, anyway), but they require them! If you put most of them in the kinds of conditions we like, they would die.

This list is posted on NASA's Astrobiology Institute web site: astrobiology.arc.nasa.gov/overview.html

Hottest	113°C	*Pyrolobus fumarii* (Vulcano Island, Italy). Earth's average surface temperature is 15°C
Coldest	-15°C	*Crypotendoliths* (Antarctica)
Deepest underground	3.2 km underground	These bacteria live in the spaces between rock grains in the Earth's crust and are exposed to high levels of pressure, heat, and radiation.
Most acidic	pH 0.0	These bacteria grow in caves. The acid-base scale is called the pH scale where 0 is the most acidic and 14 is the most basic. Most life lives within a pH range of 5 to 8.
Most basic	pH 11	Alkaliphilic bacteria are found in areas where large bodies of water have evaporated and left behind layers of alkaline (i.e., basic) minerals.
Highest radiation dose	5 million rads	*Deinococcus radiodurans* is a common soil organism. A dose of 1000 rads will kill a person. Less than 1 rad per year is normal, and zero rads is ideal.
Longest period in space	6 years	*Bacillus subtilis* living in a NASA satellite that exposed test organisms to the extreme conditions of outer space.
Highest pressure	1200 times atmospheric pressure	This was a bacillus living at the bottom of the Marianas Trench, the deepest point beneath Earth's oceans. Typically, atmospheric pressure at sea level is 1013 millibar (14.7 pounds per sq. inch.)
Saltiest	30% salt	Halophilic bacteria live in water with a 30% salt content. By comparison, seawater and human blood are about 3.5% salt. Fresh water has very little salt.

Why are all these extremophiles bacteria or bacteria-like organisms, rather than being more like cockroaches, plants, or us? Mostly because extremophiles are very simple organisms compared with multicellular life. With fewer parts and fewer internal processes to coordinate, less can go wrong. When something does go wrong, it is easier to repair the damage and keep the organism living.

Some people will only be happy when we find a Hollywood-style alien. However, astrobiologists would be ecstatic if we found evidence of even a simple microbe anywhere beyond Earth. That would suggest that life occurs whenever the conditions are right. Also, once microbes inhabit a world, it opens up possibilities for the development of more advanced life. The first life on Earth was microbial and look at us now!

Before starting today's activity, answer the following questions.

1. What is an extremophile?

2. Why are extremophiles either bacteria or bacteria-like?

3. Could humans be considered extremophiles? Explain.

4. Complete this table with information on the conditions that life can tolerate.

Environmental Condition	Maximum Level Tolerated by Life	Minimum Level Tolerated by Life	Typical Level for Humans
Temperature			
Acid-Base Levels			
Salt Levels			
Radiation Levels			

What can life tolerate?

Think About It

Name ______________________________

Date ______________________________

1 How can life and conditions on Earth be used as a model for life on other worlds?

2 If you were able to send a test tube of one kind of extremophile to Mars, which extremophile would you choose? Why?

3 If you were able to send a test tube of one kind of extremophile to Europa, which extremophile would you choose? Why?

4 If you could genetically engineer a new extremophile so that it had the traits of two different kinds of extremophiles, which two traits would you merge if your extremophile were to live on Mars? Europa? Explain.

(continues)

What can life tolerate?

Think About It (continued)

5 Describe the kind of extraterrestrial life that we are most likely to find in our solar system. Why do you think it is the most likely kind?

6 What will finding evidence of microbial life on another world teach us about life in general?

7 Draw two pictures: one of the kind of extraterrestrial life we might reasonably expect to find in our solar system and the other of what you think most people think is out there. If they are different, explain why you think they are different.

What can life tolerate?

Rules for *Life on the Edge* Card Game

LIFE ON THE EDGE

Today you will play a card game that shows how life and conditions on Earth can be used as a model for life on other worlds. The rules are similar to Rummy, and the game is best played with two to four students.

1. Deal five cards to each player and place the remainder face down between the players. This will be the *draw deck*. Turn one card face up next to the draw deck.
2. The first player takes either the upturned card or the top card of the draw deck.
3. The player sees if he or she has a set (one card from each category). To be a valid set, the organism must be able to live in the Earth and possible extraterrestrial habitats.

Organism Card	Earth Habitat Card	Possible Extraterrestrial Habitat Card
O describes a specific type of extremophile	E describes a specific habitat on Earth where this extremophile might be found	H describes an extraterrestrial habitat with similar characteristics to the Earth habitat that could be home to extremophiles or extremophile-like life

4. If the player has a valid set, he or she must lay it down, read the three cards aloud, and explain why it is reasonable to think that an organism might exist on this other world. Other players can challenge the set if they disagree.
5. The player discards a card and play continues in a clockwise rotation.
6. The next player may take the discarded card or select the top card of the draw deck.
7. Play continues until the first person goes out. If all the cards from the draw deck have been drawn, shuffle the discarded cards and use them as a new draw deck.

The Makeup of the 48 Cards in the Deck

Condition	O	E	H
Hot	4	4	4
Cold	4	4	4
Acid	2	2	2
Salt	3	3	3
Radiation	3	3	3

Organism Card
Cold-Loving Bacteria

Little Known Fact: Scientists have found *Cryotendoliths* living at minus 15°C. Earth's average surface temperature is 15°C.

Organism Card
Cold-Loving Bacteria

Little Known Fact: Scientists have found *Cryotendoliths* living at minus 15°C. Earth's average surface temperature is 15°C.

Organism Card
Cold-Loving Bacteria

Little Known Fact: Scientists have found *Cryotendoliths* living at minus 15°C. Earth's average surface temperature is 15°C.

Organism Card
Cold-Loving Bacteria

Little Known Fact: Scientists have found *Cryotendoliths* living at minus 15°C. Earth's average surface temperature is 15°C.

Organism Card
Heat-Loving Bacteria

Little Known Fact: Scientists have found *Pyrolobus fumarii* living in 113°C water.

Organism Card
Heat-Loving Bacteria

Little Known Fact: Scientists have found *Pyrolobus fumarii* living in 113°C water.

Organism Card
Heat-Loving Bacteria

Little Known Fact: Scientists have found *Pyrolobus fumarii* living in 113°C water.

Organism Card
Heat-Loving Bacteria

Little Known Fact: Scientists have found *Pyrolobus fumarii* living in 113°C water.

Organism Card
Radiation-Tolerant Bacteria

Little Known Fact: Scientists have found *Deinococcus radiodurans* living after being exposed to radiation levels of five million rads. It can tolerate high levels of both ultraviolet radiation and radioactive decay. The lethal dose for humans is 1000 rads.

Organism Card
Radiation-Tolerant Bacteria

Little Known Fact: Scientists have found *Deinococcus radiodurans* living after being exposed to radiation levels of five million rads. It can tolerate high levels of both ultraviolet radiation and radioactive decay. The lethal dose for humans is 1000 rads.

Organism Card
Radiation-Tolerant Bacteria

Little Known Fact: Scientists have found *Deinococcus radiodurans* living after being exposed to radiation levels of five million rads. It can tolerate high levels of both ultraviolet radiation and radioactive decay. The lethal dose for humans is 1000 rads.

Organism Card
Acid-loving Bacteria

Little Known Fact: Scientists have found bacteria growing on the walls of caves living at 0.0 pH. Most organisms live within a pH range of 5 to 8.

Organism Card
Salt-Loving Bacteria

Little Known Fact: Scientists have found halophilic bacteria living in water that is 30% salt. By comparison seawater and human blood are about 3.5% salt.

Organism Card
Salt-Loving Bacteria

Little Known Fact: Scientists have found halophilic bacteria living in water that is 30% salt. By comparison seawater and human blood are about 3.5% salt.

Organism Card
Salt-Loving Bacteria

Little Known Fact: Scientists have found halophilic bacteria living in water that is 30% salt. By comparison seawater and human blood are about 3.5% salt.

Organism Card
Acid-loving Bacteria

Little Known Fact: Scientists have found bacteria growing on the walls of caves living at 0.0 pH. Most organisms live within a pH range of 5 to 8.

Earth Habitat Card

Salt domes and brine are often found in association with petroleum deposits.

Earth Habitat Card

The Arctic ice cap is made of water ice.

Earth Habitat Card

Water ice over two kilometers thick covers Antarctica. The coldest temperature on Earth, minus 89°C, was recorded in Antarctica.

Earth Habitat Card

Greenland is covered with a two-kilometer-thick sheet of water ice.

Earth Habitat Card

The evaporation of large bodies of salt water has covered large areas of land with thick layers of salt.

Earth Habitat Card

Volcanic vents occur all along the 17,000 miles of Earth's mid-oceanic ridges. The water injected into the ocean environment is extremely hot.

Earth Habitat Card

Hot springs occur when groundwater is heated and rises to the surface.

Earth Habitat Card

Processes in the Earth's crust produce extremely hot groundwater.

Earth Habitat Card

Contact between volcanic magma and underground water produce pockets of hot water.

Earth Habitat Card

The Arctic tundra has a layer of permafrost beneath it. Permafrost is soil locked in water ice.

Earth Habitat Card

Natural deposits of uranium can produce areas with high levels of radiation.

Earth Habitat Card

When our atmosphere's ozone layer gets thin, Earth's surface can receive dangerous levels of harmful ultraviolet radiation.

Earth Habitat Card

Acidic groundwater is found beneath much of the Earth's crust.

Earth Habitat Card

Acidic groundwater dissolves certain kinds of rocks, forming caves and producing an acidic environment for life.

Earth Habitat Card

Salt occurs in Earth's ocean water. The salt concentration can rise dramatically as water evaporates from enclosed bodies of sea water such as tide pools and enclosed bays.

Earth Habitat Card

Radiation in the Earth's crust comes from the decay of radioactive elements such as uranium.

Possible Extraterrestrial Habitat

Just beneath Europa's surface, there may be large pockets of salty brine.

Possible Extraterrestrial Habitat

During its first two to three billion years, Mars had water and volcanic activity. This combination would likely produce hot springs and underground pockets of hot water.

Possible Extraterrestrial Habitat

Europa's ocean is probably very salty.

Possible Extraterrestrial Habitat

The decay of radioactive elements such as uranium in the Martian crust would create high levels of radiation.

Possible Extraterrestrial Habitat

Mars may have a layer of water beneath its surface. On Earth, such groundwater is often acidic.

Possible Extraterrestrial Habitat

Acidic groundwater dissolves certain kinds of rocks, forming caves. Mars may have these kinds of rocks, resulting in an acidic environment for life.

Possible Extraterrestrial Habitat

Ultraviolet radiation and charged particles from the sun bombard the surface of Mars, which is completely unprotected from these kinds of harmful radiation.

Possible Extraterrestrial Habitat

Salt layers form when large bodies of salty water evaporate. Mars may have had large bodies of water that have since evaporated, possibly leaving layers of salt.

Possible Extraterrestrial Habitat

Ultraviolet radiation bombards the surface of Europa, which is completely unprotected from this kind of harmful radiation.

Possible Extraterrestrial Habitat

Processes in the Martian crust may heat water below the surface, producing pockets of hot groundwater.

Possible Extraterrestrial Habitat

The Northern Polar ice cap on Mars is made of water ice.

Possible Extraterrestrial Habitat

The core of the Southern Polar ice cap on Mars seems to be made of water ice.

Possible Extraterrestrial Habitat

Most of the Martian surface has a layer of permafrost beneath it. Permafrost is soil locked in water ice.

Possible Extraterrestrial Habitat

Europa is completely covered by a one- to ten-kilometer-thick shell of water ice.

Possible Extraterrestrial Habitat

Evidence suggests that Europa may have considerable volcanic activity beneath its ocean. This volcanic activity would provide Europa's ocean with large amounts of hot water.

Possible Extraterrestrial Habitat

The Martian surface has deposits of a kind of iron oxide called hematite. Hematite is often associated with organisms living in hot springs.

The Astrobiology Biogeocatalysis Research Center at Montana State University

Our team supports the work of the NASA Astrobiology Institute (NAI), a multidisciplinary umbrella for conducting research on the origin and evolution of life on Earth and elsewhere in the universe.

The origin of life, sustainable energy, and global climate change are intimately linked, and the answers we seek to solve our energy needs of the future are etched into Earth's history. ABRC's work supports NASA's missions, such as Mars exploration and possibilities of habitation of other worlds. Our research also focuses on the future of life on Earth. These efforts support the fundamental groundwork for Goal 3 (Origins of Life) of the NASA Astrobiology Roadmap.

ABRC involves investigators with expertise in geochemistry, experimental and theoretical physical chemistry, materials science, nanoscience, and iron-sulfur cluster biochemistry who work to define and conduct integrated research and education in astrobiology.

We are proud of our interdisciplinary research and teaching, and are committed to communicating and educating the public about our science and helping to train and inspire the next generation of scientists.

The nearby natural laboratory of Yellowstone National Park provides ABRC with unique field research opportunities. Life in the extreme environments of Yellowstone's thermal features is thought to resemble conditions of early Earth. Yellowstone's abundant and unique thermal features give researchers insights into the origin, evolution and future of life.

Whether you are a potential MSU student, a research investigator, a teacher or a citizen, we welcome you to the world of astrobiology. ABRC is committed to sharing our work and its impact with the people of Montana and beyond, through formal and informal education; public outreach; and communications to many different audiences.

Our outreach and education activities are strengthened by many factors, including MSU's proximity to Yellowstone National Park, the expertise and experience of our faculty and close partners, the outstanding commitment from our MSU students to share their work with the public, and a rich network of partners, including the Montana Library Association, Museum of the Rockies, Space Public Outreach Team and Hopa Mountain. We also work closely with the other teams from the NASA Astrobiology Institute.

Please feel free to contact us with any questions, and enjoy exploring our website: **http://abrc.montana.edu**

MONTANA STATE UNIVERSITY | EXTENDED UNIVERSITY

MONTANA STATE UNIVERSITY | Astrobiology Biogeocatalysis Research Center

This learning module was developed by Montana State University Extended University in collaboration with the Astrobiology Biogeocatalysis Research Center at Montana State University. For additional astrobiology education resources, visit http://abrc.montana.edu/outreach/ and for even more research-based educational resources for